Web-based Education &Training for Illicit Trafficking and Consequence Management associated with Nuclear and Radiological Terrorism[1]

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Abstract: The NUCLEONICA nuclear science portal (www.nucleonica.net) is currently being extended to include a variety of tools specifically for education and training purposes in illicit trafficking and consequence management associated with nuclear and radiological terrorism. In the following paper we describe the web applications currently under development and training course activities based on these modules.

Keywords: Nucleonica, web applications, illicit trafficking, consequence management, radiological dispersion event, gamma spectrometry, Monte Carlo, dosimetry, shielding, training courses.

1. Introduction

NUCLEONICA [1] is a nuclear science web portal from the European Commission's Joint Research Centre. The portal provides a customisable, integrated environment and collaboration platform for the nuclear sciences using the latest internet "Web 2.0" technology. NUCLEONICA is aimed at professionals, academics and students working with radionuclides in fields as diverse as the life sciences (e.g. biology, medicine), the earth sciences (e.g. geology, meteorology) and the more traditional disciplines such as nuclear power, health physics and radiation protection. In the following, a brief summary of the new modules is presented.

2. Radiological Event Scenario Analysis

In this module the dispersion of radioactivity and dose estimates are based on the Wedge model [2-4]. Utilization of the wedge model with respect to radiological dispersion events (RDE) provides a basic understanding of the dispersal of a radioactive plume following an RDE. This is because both the temporal and the spatial evolution of the radioactive cloud are fundamental features of the wedge

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model. Thus, identification of the key physical processes at work make it possible to estimate the public health risk associated with the source terms, and to improve on the understanding of the phenomena associated with RDEs. Work is currently underway on an online implementation of the wedge model for scenario building within the NUCLEONICA framework (see www.nucleonica.net).

2.1 Model Parameters

The wedge model assumes that the detonation of an RDE will involve a plume of finely dispersed aerosol moving downwind with a given wind velocity u and dispersing in the cross-wind direction with a characteristic opening angle. The aerosol in the plume is assumed to be uniformly distributed in both the cross-wind (lateral) direction and throughout the constant plume height H. Fig. 1 gives a schematic representation of how the plume evolves as the downwind distance r, and therefore the time since detonation (t = r/u), increases. Crucially, the amount of aerosol in the cloud at a given time after detonation - i.e. the shaded volume of width dr in the figure - will decrease as time increases. The mechanism responsible for this decrease is due to the radioactive aerosol falling to the ground with a given deposition velocity (v), and therefore no longer posing an inhalation risk.

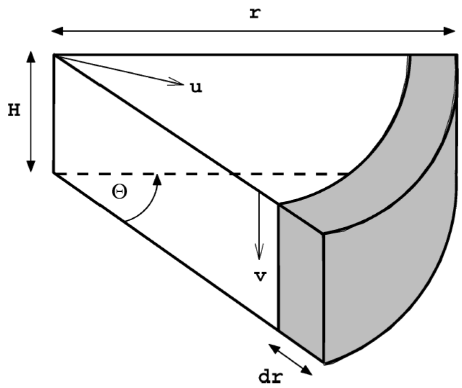

Figure 1: The wedge model involves the dispersal of radioactive aerosol as a function of downwind distance r given an initial wind speed u, opening angle θ and height H. The shaded volume highlights the position of the aerosol at a given time t after detonation.

The list below gives the wedge model parameters:

- source activity A_0
- distance r downwind of detonation point
- height of the cloud H
- wedge opening angle θ
- wind velocity u
- rate of inhalation R_{inh}, and effective dose coefficient $e_{inh}(50)$
- population density at a particular point $\rho(r)$
- deposition velocity v

The wedge model has an intrinsic characteristic timescale, defined by the deposition mechanism. This allows access to detailed information on the airborne activity and the committed dose by inhalation as a function of time and distance. The fundamental parameter is the deposition velocity: the speed at which aerosol particles fall to earth, which, when combined with the cloud height, defines an average time $\tau = H/v$, range L = uτ = uH/v, for an aerosol particle to fall to the ground.

2.2 Calculation of Committed Dose

From the basic properties of the wedge model, it can be shown that the committed dose for inhalation is given by

$$CD_{inh} = \frac{k_a e_{inh}(50) A_0 R_{inh} \rho_0}{v}$$

The above expression for the collective dose received by the affected population in the wedge model is independent of the wind speed, opening angle, and plume height, and for a given population density and source term it depends only on the deposition velocity. Indeed, one of the great advantages of the wedge model is this very simple relationship for the collective dose (the best measure of public health consequences), which is not available in more complex models. The results from a typical calculation are shown in Fig. 2.

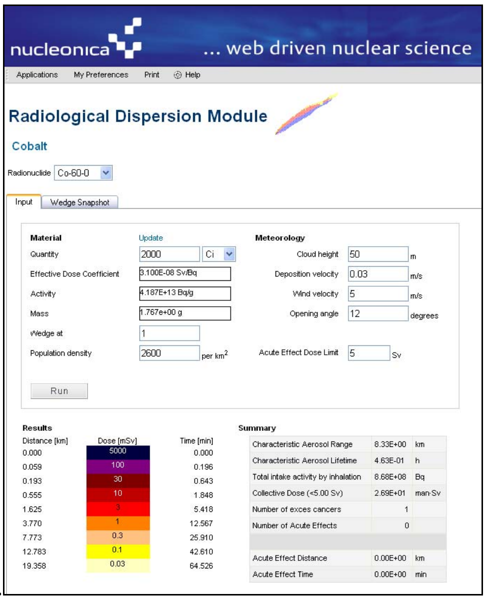

Figure 2: The Wedge model user interface. Users can select the nuclide (Co-60), its activity (1 Ci) and set the various meteorological parameters (wind speed = 5 ms^{-1}, etc.). In the results summary, the collective dose is given with an estimate of the number of excess cancers together with information on the aerosol dispersion.

3. Gamma Spectrum Generator

The generator allows the user to obtain easily the model γ-spectra for an arbitrary mixture of known γ-emitting nuclides and user-specific detection system. The currently implemented measurement geometry model [5] represents a point-like gamma-ray source located on the axis of a cylindrically symmetric NaI or HPGe crystal and separated from it by a number of inactive material layers, as shown in Fig. 3. The inactive layers include various detector construction elements, such as the inactive Ge, detector cap, crystal reflector and crystal packaging. In addition, up to 6 absorbing filters made of Al, Cu, Pb, Fe, Sn, and polyethylene can be introduced into the model to simulate measurement conditions specific to the shielded and containerised γ-sources.

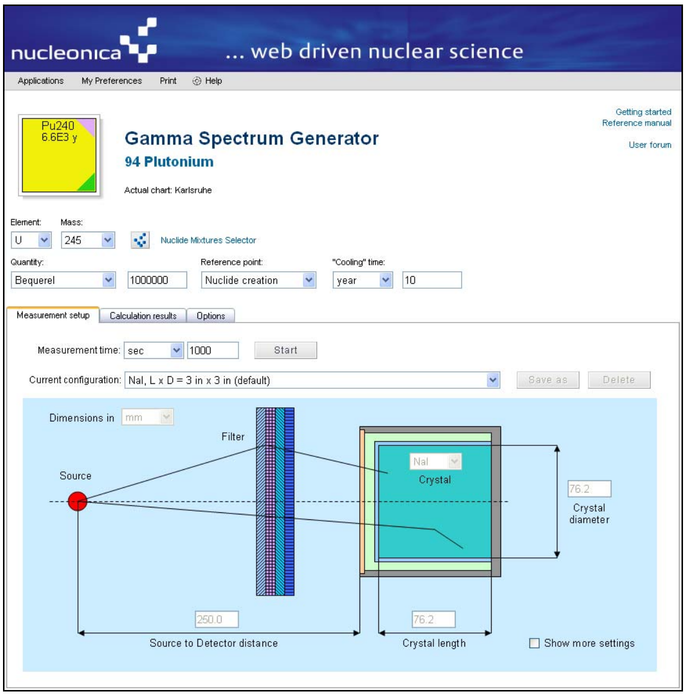

Figure 3: NUCLEONICA's Gamma Spectrum Generator web-page. The tab with basic measurement geometry setup controls is shown.

The γ-spectrum is constructed by summing up detector response profiles, generated for individual γ-rays and appropriately normalized to take into account γ-emission probabilities and actual number of decays of respective nuclides, occurred during spectrum measurement. The decay mode and source "cooling" time interval can be also specified to allow the contribution of daughter products accumulated to the resulting spectrum. With these features one can easily simulate and observe, for instance, the differences between γ-spectra taken from the uranium ore and from natural and enriched U samples at the specified point of time after the chemical separation. The detector specific energy resolution and user-specified ADC parameters are taken into account to produce a realistic γ-spectrum.

To ensure fast and accurate modelling, the detector responses are generated by interpolation of the data from the extensive detector response database that has been pre-calculated using a dedicated Monte Carlo program. The database contains the peak efficiencies and continuum profiles, which were parameterised on the 4-dimensional grid of the crystal dimensions, source-to-crystal distance and γ-ray energy. The crystal dimension grid ranges from 2 cm to 12 cm for both crystal length and diameter, thus including a variety of γ-detection instruments used in real practical applications. The γ-ray energy grid spans the 10 keV - 10 MeV interval, thus covering the useful energy ranges of radionuclide decay and prompt neutron capture gammas. A unique feature of the response profiles used is the "backscatter peak" continuum that is added to the resulting γ-spectrum.

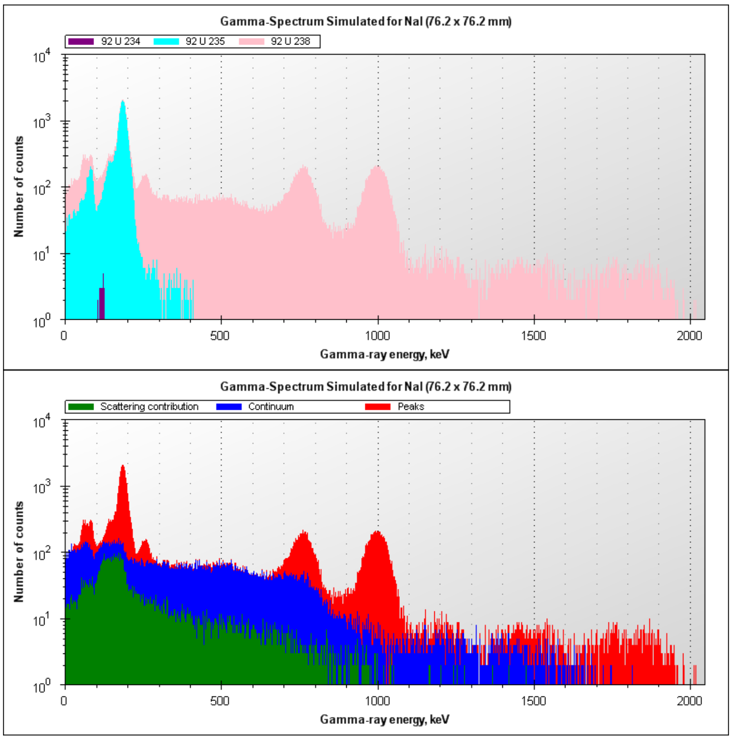

Fig. 4: The γ-spectrum modelled for a 10-year-aged natural U sample and 3"×3" NaI detector. The two diagrams show different presentations of the same spectrum. The top diagram shows the separate contributions form the parent and daughters of U-234, U-235, U-238. The bottom diagram shows the contributions from the peak and continuum components of the spectrum.

The contribution of this additional continuum can be scaled to simulate mpre accurately the influence of the γ-ray scattering in the shield and other objects that surround source and detector. Different parts of the spectra and nuclide specific contributions can be easily visualized and studied using the interactive graphical tools provided. Fig. 4 shows the γ-spectrum component visualization examples in

the case of the 10-year-aged natural U sample measured with the 3"×3" NaI detector.

In addition to the spectrum graphs, an extensive set of the spectrum associated data, including the minimum detectable activities, filter attenuation corrections and detection efficiencies, is available in Excel and plain text formats. These data can be useful in advanced training sessions for professionals and also in resolving real practical problems. Further information on the Gamma Spectrum Generator can be found in the NUCLEONICA wiki [6].

4. easyMonteCarlo

This simulation module is based on the easyMonteCarlo web-service. The service is capable of performing dosimetry and shielding calculations for any complex radiation object consisting of enclosed parallelepipeds, spheres and cylinders filled in with arbitrary user-defined materials. Such an object can include a number of point-like sources as well as active volumes with uniform spatial distribution of radioactivity. An arbitrary mixture of γ-emitting nuclides can be assigned to each source inside the object. The neutron sources can include mixtures of spontaneous fission nuclides, such as ^{238}Pu, ^{240}Pu, ^{242}Pu, ^{242}Cm, ^{244}Cm, and ^{252}Cf. In addition, both γ - and neutron emitting sources can be defined in the form of line spectral distributions.

The basic quantity, which is evaluated by the service, is the particle flux at a given point in the three-dimensional space. The γ - and neutron equivalent dose rates are obtained by convoluting the particle flux with the respective flux-to-dose-rate conversion coefficients taken from the recent evaluation [7]. The "scoring" of the particle flux is implemented based on the next-event-estimator approach, or the so-called point detector tally. Such virtual detectors can be placed at an arbitrary location around the defined radiation object and provide evaluations for the cumulative and spectrum dependent particle flux and dose rates. By default the spectral information includes particle flux and dose rate values for three energy regions. These regions are < 100 keV, 100 keV – 1 MeV, and > 1 MeV for photons, and < 0.5 eV (thermal neutrons), 0.5 eV – 100 keV (epithermal neutrons), and > 100 keV (fast neutrons) for neutrons. In addition, the user can define his own set of energy intervals and, thus, obtain detailed spectral information about the particle flux or dose rate at the particular points of space.

Flux and dose build-up factors are another two quantities which are automatically calculated by the web-service. These quantities give useful information on the energy and geometry dependent contribution of the scattered radiation to the resulting particle flux and dose rate values. It is of importance to note that the Monte Carlo is the only method that can provide such estimates for almost any complex geometry of a radiation object.

Although the web-service provides a rather high level of flexibility in terms of the radiation object geometry and calculated quantities, the current implementation of the related NUCLEONICA web-application contains only a sub-set of these features. The easy-to-use, intuitive interface shown in Fig.5 represents a radiation source in the finite shield geometry. The source and detector are located at given distances on the opposite sides of the rectangular shield, which is characterized by the three linear dimensions (thickness, width, and height). The source can be ei-

ther a point or a sphere with uniform distribution of the target nuclide or nuclide mixture over the volume. The shield and source materials can be chosen from the lists of the single elements and compounds provided.

The calculation process is organized in repetitive steps by slicing the number of trials. After the next set of trials is executed, the user window is updated to show the current results in numerical and graphical forms. The graphical representation shows the calculated values as a function of the number of trials executed so far. The calculation can be terminated or interrupted by the user at every step, but normally after the required statistical precision has been achieved (<1%).

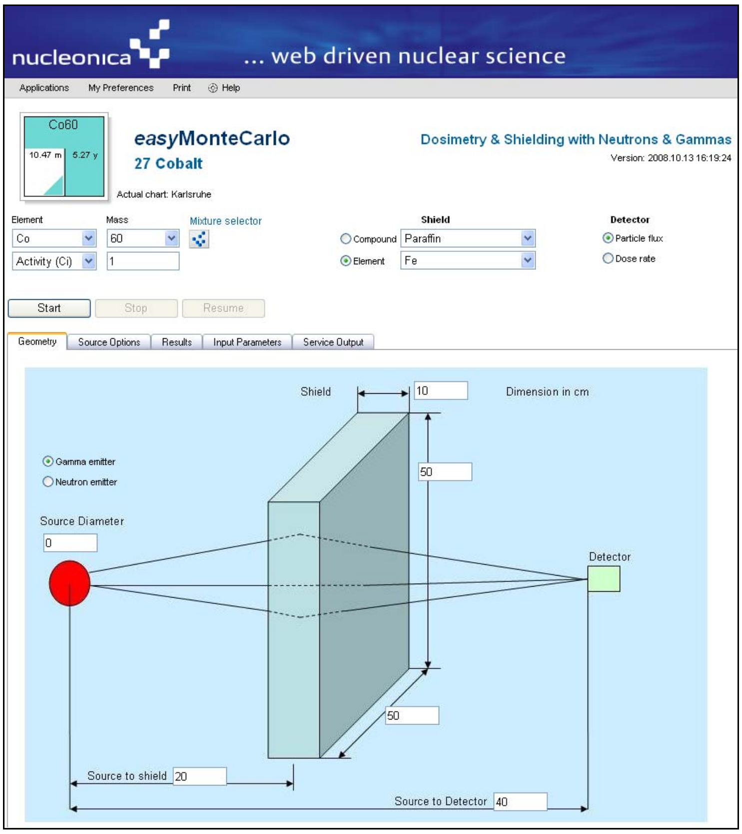

Fig. 5: NUCLEONICA's easyMonteCarlo web-page showing the currently implemented shielding geometry.

An example of the easyMonteCarlo calculation results is shown in Fig. 6. The figure demonstrates the photon flux energy distribution from the 1 Ci ^{60}Co source with 10 cm × 50 cm × 50 cm iron shield. The source-to-shield and source-to-detector distances are 20 cm and 40 cm respectively. The contributions of the direct and scattered photons to the total flux are indicated on the graph by the red and blue columns respectively.

In the future it is planned to implement more sophisticated sources and shield geometries including, for instance, multilayer heterogeneous shields. It is also

planned to build an interconnection between the easyMonteCarlo and Gamma Spectrum Generator modules to allow more realistic simulations of the γ-spectra from voluminous and shielded sources.

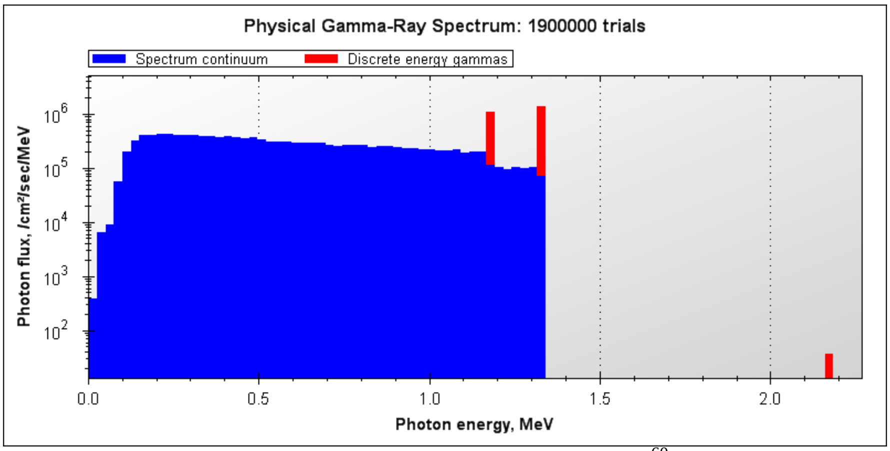

Fig. 6: The photon flux energy distribution from a shielded ^{60}Co source simulated using the NUCLEONICA's easyMonteCarlo web service. The contributions of the direct (red) and scattered photons (blue) to the total flux are indicated by the red and blue columns respectively. In addition to the well-known lines at 1.17 and 1.33 MeV, the weaker line at 2.16 MeV can also be seen.

5. Training Courses

Training courses are held on a regular basis [8], once or twice per year at both the Institute for Transuranium Elements in Karlsruhe, Germany and at other training centres in Europe. Recent courses have been jointly organised by the Josef Stefan Institute in Slovenia and Ege University in Turkey [9].

The courses introduce the basic concepts of illicit trafficking, nuclear forensics and consequence management, and are suitable for participants from the nuclear industry, nuclear research organizations, universities, regulatory authorities and nuclear medicine institutes. Lectures, presented by experts in their respective fields, are followed by examples, exercises and a series of “hands-on” case studies based on the use of the NUCLEONICA web-based applications to give the user direct experience in the above areas.

In view of the multi-disciplinary nature of the subject and its importance in today’s society, there is an urgent need for education and training in this area. In this course, participants can consult with experts in the field, develop a thorough understanding of the basic concepts, obtain an overview of the multi-disciplinary nature of the subject, and receive direct hands-on experience with NUCLEONICA web-based applications

As part of its "Enlargement and Associated Initiatives" activity, the European Commission sponsors participants from Candidate Countries, Potential Candidate Countries as well as European Neighbourhood Partner (ENP) Countries. Further details and information on future courses can be found on the NUCLEONICA wiki [10].

Conclusions

The three new web-based modules for education and training purposes have been described.
With the source term and *Radiological Event Scenario Analysis* module, the consequences of a radiological dispersion event (RDE) can be estimated. Two separate modelling stages are accounted for: (i) dispersion of radioactive aerosol under given meteorological conditions, (ii) public health consequences due to exposure to the radioactive aerosol. In order to describe the evolution of a radioactive aerosol plume resulting from an RDE, the wedge model is used. This gives a simple, intuitive account of the dynamics governing the dispersal of a radioactive aerosol cloud under given meteorological conditions.
With the *Gamma Spectrum Generator* [5], the user can model γ-spectra for arbitrary mixtures of known γ-emitting nuclides and user-specific detection systems based on a HPGe or NaI crystal. The generator presents an efficient visual teaching aid that is especially useful in training facilities which have restrictions on the use of radioactive substances, or when sources of special interest (e.g. spent fuel, enriched U, weapon grade Pu or other highly radiotoxic materials) are not readily available.
Fast and accurate dosimetry and shielding calculations for gammas and neutrons are possible with NUCLEONICA's powerful on-line *easyMonteCarlo* web-service and associated web-based application. The easy-to-use intuitive interface allows the user to define any complex radiation object. Possible radiation sources include mixtures of gamma-emitting or spontaneous fissioning nuclides. These features make the *easyMonteCarl*o web-service useful for both training purposes and real case studies associated with illicit trafficking and consequence management activities.
Training courses based on these and additional web-based modules, for illicit trafficking and consequence management associated with nuclear and radiological terrorism, are provided on a regular basis within our organisation.

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